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Collaborative Innovation in Construction Supply Chain under Digital Construction: Evolutionary Game Analysis Based on Prospect Theory

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Abstract: In the context of Digital Construction (DC), collaborative innovation in the construction supply chain (CSC) is crucial for long-term competitiveness. However, transparent information flows and fickle market circumstances hinder enterprises from actively participating in collaborative innovation, making it challenging to establish effective incentive mechanisms. To achieve sustained and stable collaborative innovation, an evolutionary game model of collaborative innovation between core enterprises and member enterprises in the CSC under DC based on Prospect Theory is constructed. Five equilibrium scenarios and evolutionary stability strategies are analyzed, and the corresponding stability conditions are obtained. Finally, the impact of different parameters on strategy selection are analyzed by numerical simulation. The results indicate that the balance between knowledge sharing and knowledge leakage is the premise of the positive impact of DC technology on collaborative innovation. Moreover, the adjustment of gain sensitivity and loss sensitivity is the key to enhancing managerial enthusiasm for collaborative innovation. Furthermore, the design of income distribution and innovation incentives must adhere to the reciprocity principle, while subsidies from owners demonstrate a prominent positive impact on collaborative innovation. This paper systematically expounds the dynamic influence of DC technology application, knowledge spillover effects, and managerial cognitive structures while confirming the intrinsic effect of innovation incentive mechanisms. It provides substantial theoretical reference and management enlightenment for promoting the development of collaborative innovation in the CSC under DC.

Keywords: digital construction; construction supply chain; collaborative innovation; prospect theory; evolutionary game

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1. Introduction

With the rapid advancement of today's digital economy, the technological changes driven by Industry 4.0 are propelling a continuous wave of digitalization within the construction industry [1]. The increasing adoption of digital technologies such as Building Information Modeling (BIM), Virtual Design and Construction, and Direct Digital Manufacturing signifies the rise of Digital Construction (DC), infusing fresh vitality into the construction industry [2]. Nonetheless, as DC advances, merely adopting technology falls short of matching the relentless evolution of technologies and volatile market demands, thus intensifying the challenges to the industry's capacity for innovation. For an extended period, the lack of collaboration has been a key barrier hindering the progress of innovation in the construction industry [3].

In the realm of manufacturing, the effects and advantages of supply chain collaborative innovation have garnered widespread recognition [4]. This collaborative model underscores the synergy between core enterprises and member enterprises. By commencing from a holistic system perspective, supported by collaborative mechanisms and technologies, it takes information sharing as the basis to achieve the goal of maximizing the benefits of the supply chain, thereby enhancing overall competitiveness [5]. Similarly, in the construction industry, the construction supply chain (CSC) is a network chain structure that revolves around core enterprises (project general contractors) and is jointly established with member enterprises (subcontractors, material suppliers, equipment suppliers, etc.), embodying the functional integration of activities across individual enterprise boundaries in construction projects [6]. To adapt to the rapid technological and market changes amid digital transformation, core enterprises need to bolster the innovation capabilities of member enterprises, fostering overall performance enhancements to sustain long-term industry competitiveness. Likewise, member enterprises are inclined to engage in collaborative innovation endeavors, leveraging core enterprises' support to provide superior resources and achieve mutual benefits and synergistic outcomes through complementary advantages [7]. However, the complex nature and fragmented structure of construction projects have historically impeded efficient information sharing, thereby constraining collaborative innovation in the CSC.

The increasing prominence of DC presents new opportunities for collaborative innovation in the CSC. DC technology, with BIM at its core, provides a more cohesive collaborative platform. Its effective implementation enhances the speed of information exchange and the efficiency of knowledge sharing in the CSC, serving as a significant driver for enhancing collaborative innovation benefits [7]. However, DC also brings a host of new challenges. Notably, information transmission under DC technology is characterized by transparency and openness, posing potential risks of breaching information confidentiality and harming innovation benefits, thus causing conflicts among enterprises engaged in collaborative innovation with different interest needs [8]. Additionally, the market and technology environment under DC is marked by the rapid change, which introduces uncertainties into the innovation process [9] and further leads to managers, as the conduit through which enterprises perceive external conditions, finding it difficult to objectively evaluate the expected benefits due to differences in cognitive structures and subjective biases in decision-making [10]. Considering the aforementioned factors, achieving sustained and stable collaborative innovation among enterprises solely through DC technology application, in the absence of intervention and incentive of institutions or protocols, remains challenging [11]. The existing literature on collaborative innovation under DC still predominantly focuses on a singular perspective of technology application, and some research only provides a systematic conceptual framework in the form of descriptive analysis [12]. To achieve sustained and stable collaborative innovation in the CSC under DC, it is necessary to conduct a more comprehensive examination of various factors from a systematic perspective. Evolutionary game theory provides a reliable analytical framework for systematically studying the evolutionary mechanism and stable strategies of group decision-making [13]. Moreover, Prospect Theory (PT) aptly describes the risk avoidance and subjective perception biases of game players [14]. Consequently, this study utilizes a PT-based evolutionary game approach to analyze collaborative innovation in the CSC under DC, focusing on the following research questions:

1. How do knowledge spillover effects and DC technology application influence collaborative innovation in the CSC?
2. What managerial cognitive structures can mitigate the impact of environmental uncertainty under DC?
3. What innovation incentive mechanisms can enhance collaborative innovation initiative in the CSC?

To answer these questions, Section 2 reviews the relevant academic research. Section 3 constructs and analyzes the evolutionary game model. Section 4 illustrates the numerical analysis through model simulation. Section 5 discusses the main research results. Section 6 summarizes this study and concludes management implications.

2. Literature Review

2.1. Connotation of DC

The widespread adoption of BIM marks the beginning of a new era for the construction industry. BIM provides an integrated information system for construction projects and significantly improves project implementation by facilitating information exchange and asset management [15]. Under this trend, to give full play to the effects of BIM, the integrated application of different digital technologies and BIM has further attracted extensive attention from industry sectors and academics [16–18].

As a construction mode integrated with a digital technology application, Tetik et al. [2] outlined a novel operational management paradigm, termed Direct DC. Likewise, Ding [19] concluded that the innovative integration mode of the new generation of information technology and engineering construction entails realizing digitally driven engineering project construction, termed DC, based on the informatization of engineering construction elements. However, although academics have analyzed DC from a technology integration perspective, they also emphasized that in order to better understand and cope with the challenges and opportunities brought by DC, it is essential to focus not only on the improvement of construction technology but also on transformations in business philosophy and industrial ecology. Responding to this call, researchers have highlighted a high level of innovation as an important feature of the robust development of the digital economy [20].

2.2. Collaborative Innovation under DC

Innovation has become the key driver for enterprises to maintain competitiveness, and the construction industry is no exception [21]. With the popularity of DC, construction enterprises are increasingly pursuing innovative success through collaboration [22]. Firstly, DC technology such as BIM significantly improves the transparency and integration of construction projects, thus providing good technical support for knowledge sharing and becoming a key driving force for the collaborative innovation of construction projects [7]. Secondly, despite DC technology being full of potential, the application level of DC technology in the construction enterprises lags behind, which makes collaboration important [23]. Notably, the integration practice of the CSC under DC is a systematic mechanism integrating organizational information, processes, people, and enterprises. The systematic conceptual framework proposed by Liu et al. [12] provides a comprehensive overview of BIM-enabled collaborative innovation in construction, encompassing six interrelated elements, including technology application, contract formulation, information transmission, individual orientation, etc. It is essential to link these components to gain a deeper understanding of their collective roles and interconnections [24].

However, previous studies mainly focused on a single perspective and generally concentrated on simple technology application factors [11,25,26], and only descriptive analysis was conducted on the systematic role of innovation factors. Based on this, this study further discusses the systematic role of these elements through mathematical modeling, so as to promote the robust development of collaborative innovation in the CSC under DC.

2.3. PT-Based Evolutionary Game

Evolutionary game theory offers a mathematical modelling method that combines principles from game theory with evolutionary dynamics, acting as a robust tool to investigate the evolution of group decision behavior within complex systems [13]. By delving into cooperative and competitive interactions among individuals, we elucidate the evolutionary mechanisms of group decision behavior [27]. The collaborative innovation of the construction industry is essentially a competitive and cooperative game problem with complexity and dynamics [13]. Recent studies have also introduced the cooperative behavior of innovative agents under construction projects into the evolutionary game model, intuitively describing the complex influence of multiple factors and proving the applicability of the evolutionary game approach [28].

Nevertheless, traditional evolutionary game theory focuses on the foundational assumptions of bounded rationality while overlooking individuals' subjective perceptions and preferences for different outcomes. This limitation prevents it from effectively capturing the risk aversion tendencies of enterprises engaged in collaborative innovation under DC [29]. PT, proposed by Kahneman and Tversky [30], describes the behavior pattern and psychological deviation of individuals in the face of risk and uncertainty and provides a feasible way to solve this problem. Therefore, PT-based evolutionary games are an effective means to explain the evolution of strategies with risk aversion characteristics and subjective perception biases [14].

3. Model Construction and Analysis

3.1. Problem Description

Collaborative innovation in the CSC involves a distinct division of labor between core enterprises and member enterprises. Core enterprises assume leadership roles in collaborative innovation activities, developing strategies and coordinating resources to drive technological innovation. Conversely, member enterprises serve as implementers, offering specialized expertise and services to carry out technological innovation according to the strategic direction and requirements set forth by the core enterprises. Furthermore, owners, as indirect beneficiaries of collaborative innovation activities, usually incentivize these activities through subsidies without direct involvement.

However, collaborative innovation under DC brings increased complexity and uncertainty. In its 2020 report, McKinsey and Company said that introducing new DC workflows—which may be unfamiliar to some of the parties involved—can seem daunting due to a lack of digital standards and experience within the industry. Additionally, according to Deloitte's Global Digital Risk Survey 2022, the ease of replication and dissemination of knowledge brought about by digitization has made collaborative innovation a serious challenge and become an important issue in organizational management. From the above cases, it can be seen that, on the one hand, the adoption of DC technology promotes knowledge spillover effects within collaborative innovation endeavors. While this enhances knowledge sharing efficiency, it also raises concerns about knowledge leakage. On the other hand, amidst unknown benefits and potential risks within a rapidly evolving landscape, varying managerial cognitive structures lead to different perceptions of potential benefits among innovating enterprises, leading to varying degrees of risk aversion in decision-making processes. To foster the initiative of enterprises in the CSC, establishing varied innovation incentive mechanisms is crucial. This entails adjusting income distribution, providing financial support, and implementing other measures to stimulate proactive collaborative innovation. Among them, the behavior and payoff in the game are shown in Figure 1.

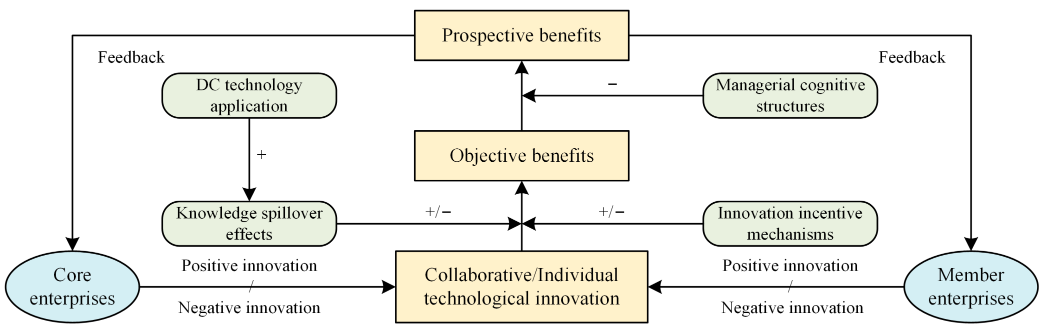


Figure 1. Behavior and payoff in the game.

3.2. Model Assumptions

Based on the above analysis, this study presents the following assumptions.

Assumption 1. *Collaborative innovation in the CSC involves two key players: core enterprises X and member enterprises Y. Core enterprises X have two strategies for innovation: positive innovation A_1 and negative innovation A_2, with respective probabilities of x and $1 - x (0 \le x \le 1)$. Similarly, member enterprises Y have two strategies: positive innovation B_1 and negative innovation B_2, with probabilities of y and $1 - y (0 \le y \le 1)$.*

Assumption 2. *When core enterprises and member enterprises collaboratively innovate, they generate innovation income u_1. When member enterprises individually innovate, they generate innovation income u_2. And $u_1 > u_2$. Additionally, when member enterprises choose a positive innovation strategy, they incur the cost of innovation c.*

Assumption 3. *The knowledge spillover effects under DC technology consist of voluntary endogenous spillover and involuntary exogenous spillover. Endogenous spillover involves knowledge sharing during collaborative innovation between core enterprises and member enterprises, which produces the positive impacts of reducing innovation costs and improving innovation income. Exogenous spillover refers to knowledge leakage from member enterprises when they innovate individually. This leakage allows core enterprises to obtain new knowledge and income from unearned "free-rider" behavior, which in turn weakens the market value of the new knowledge generated by individual innovation for member enterprises, thereby reducing their incomes. It is assumed that the influence of knowledge spillover on cost or income is linearly correlated, with $\beta_1 (0 \le \beta_1 \le 1)$ and $\beta_2 (0 \le \beta_2 \le 1)$ representing the knowledge sharing coefficient and knowledge leakage coefficient, respectively. The application of DC technology enhances the overall knowledge spillover effect, with $\alpha (0 \le \alpha \le 1)$ as the DC technology application coefficient.*

The impact of knowledge sharing on the reduction of collaborative innovation costs is represented as $\left(\frac{\beta_1{}^{1-\alpha}}{2} - 1\right)c$, and the enhancement of collaborative innovation income is represented as $\frac{\rho u_1}{\left(1 - \frac{\beta_1{}^{1-\alpha}}{2}\right)}$. Knowledge leakage leads to a decrease in the individual innovation income of member enterprises, expressed as $\left(1 - \frac{\beta_2{}^{1-\alpha}}{2}\right)u_2$, while the benefits of the core enterprise's "free rider" behavior are represented as $\frac{\beta_2{}^{1-\alpha}}{2}u_2$. To simplify the expressions, let $IS = 1 - \frac{\beta_1{}^{1-\alpha}}{2}$ and $ES = 1 - \frac{\beta_2{}^{1-\alpha}}{2}$.

Assumption 4. *The managerial cognitive structures significantly influence enterprises' decision-making behavior, characterized by PT under DC, including the certainty effect, reflex effect, loss avoidance, small probability and reference dependence [30]. PT is introduced and modified by the prospect value function V, calculated by the value function and weight function in Equation (1).*

$$V = \sum v(\Delta U) w(p_i) \tag{1}$$

Here, $v(\Delta U)$ is the value function represented by Equation (2), where ΔU indicates the gain and loss deviation from the reference point; when it is greater than or less than 0, this represents the subjective perception of the manager as a gain or loss. Moreover, $(0 \le a \le 1)$ and $b(0 \le b \le 1)$ represent the gain and loss sensitivity coefficients, respectively, and their magnitudes indicate the degree of risk aversion or the appetite of managers when they are in a gain or loss state. $\lambda(\lambda \ge 1)$ is the loss aversion coefficient, and its magnitude indicates the degree to which managers are more sensitive to the perception of loss than the perception of gain under uncertain conditions.

$$v(\Delta U) = \begin{cases} \Delta U^a, \Delta U \ge 0 \\ -\lambda(-\Delta U)^b, \Delta U < 0 \end{cases} \tag{2}$$

$w(p_i)$ is a weight function, which is a nonlinear increasing function of the objective probability $p_i(0 \leq p \leq 1)$ of decision event i, expressed by Equation (3). It satisfies $w(1) = 1$ and $w(0) = 0$ in the small probability case, $w(p_i) > p_i$, and in the rest cases, $w(p_i) < p_i$. In this study, $p(0 \leq p \leq 1)$ is set as the probability of innovation income. $r(0 \leq r \leq 1)$ is the weight coefficient, which is represented as the curvature parameter of the weight function, reflecting the degree of influence of the probability of decision events on the prospect value.

$$w(p_i) = \frac{p_i^r}{\left[p_i^r + (1-p_i)^r\right]^{1/r}} \tag{3}$$

Assumption 5. *In collaborative innovation, both parties must agree on the distribution ratio of innovation income, with the core enterprise and member enterprise distribution ratios set as* ρ *and* $1-\rho(0 \leq \rho \leq 1)$, *respectively. Additionally, when the core enterprises select a positive innovation strategy, they provide financial incentives to stimulate member enterprises to innovate, with the innovation incentive fund denoted as* σ. *Owners may provide subsidy measures for innovative enterprises based on innovation cost, with the subsidy coefficient* $\gamma(0 \leq \gamma \leq 1)$.

Based on the above assumptions, all parameters and corresponding descriptions are summarized in Table 1.

Table 1. Parameters and corresponding descriptions.

Parameter	Description
u_1	Collaborative innovation income
u_2	Individual innovation income
c	Innovation cost
$\beta_1(0 \leq \beta_1 \leq 1)$	Knowledge sharing coefficient
$\beta_2(0 \leq \beta_2 \leq 1)$	Knowledge leakage coefficient
$\alpha(0 \leq \alpha \leq 1)$	DC technology application coefficient
$a(0 \leq a \leq 1)$	Gain sensitivity coefficient
$b(0 \leq b \leq 1)$	Loss sensitivity coefficient
$\lambda(\lambda \geq 1)$	Loss aversion coefficient
$p(0 \leq p \leq 1)$	Innovation income probability
$r(0 \leq r \leq 1)$	Weight coefficient
$\rho(0 \leq \rho \leq 1)$	Income distribution ratio
σ	Innovation incentive fund
$\gamma(0 \leq \gamma \leq 1)$	Innovation subsidy coefficient

3.3. Model Construction and Solution

Based on the above description and assumptions, this study constructs four strategy combinations and analyzes the payoffs of core enterprises and member enterprises in each strategy combination.

(Positive innovation A_1, Positive innovation B_1): In this strategy combination, both core enterprises and member enterprises actively innovate, forming collaborative innovation, generating innovation income u_1 with a probability of p, and knowledge sharing occurs. Therefore, the core enterprises receive the innovation income $w(p)v\left(\frac{\rho u_1}{IS}\right)$, pay the innovation incentive fund $v(-\sigma)$, and receive the innovation subsidy $\frac{v(\gamma c)}{2}$. The member enterprises receive the innovation income $w(p)v\left[\frac{(1-\rho)u_1}{IS}\right]$, pay the innovation cost $v(-ISc)$, receive the innovation incentive fund $v(\sigma)$, and receive the innovation subsidy $\frac{v(\gamma c)}{2}$.

(Negative innovation A_2, Positive innovation B_1): In this strategy combination, the member enterprises individually innovate, generating innovation income u_2 with a probability of p, and knowledge leakage occurs. Therefore, the core enterprises receive a "free rider" benefit $w(p)v[(1-ES)u_2]$. The member enterprises receive the innovation income $w(p)v(ESu_2)$, pay the innovation cost $v(-c)$, and receive the innovation subsidy $v(\gamma c)$.

(Positive innovation A_1, Negative innovation B_2): In this strategy combination, the member enterprises individually innovate. Therefore, the core enterprises pay the innovation incentive fund $v(-\sigma)$ and receive the innovation subsidy $v(\gamma c)$. The member enterprises receive the innovation incentive fund $v(\sigma)$.

(Negative innovation A_2, Negative innovation B_2): In this strategy combination, both the core enterprises and the member enterprises engage in negative innovation, resulting in no payoffs.

Through the above analysis, the game tree and payoffs of core enterprises and member enterprises are obtained, as shown in Figure 2.

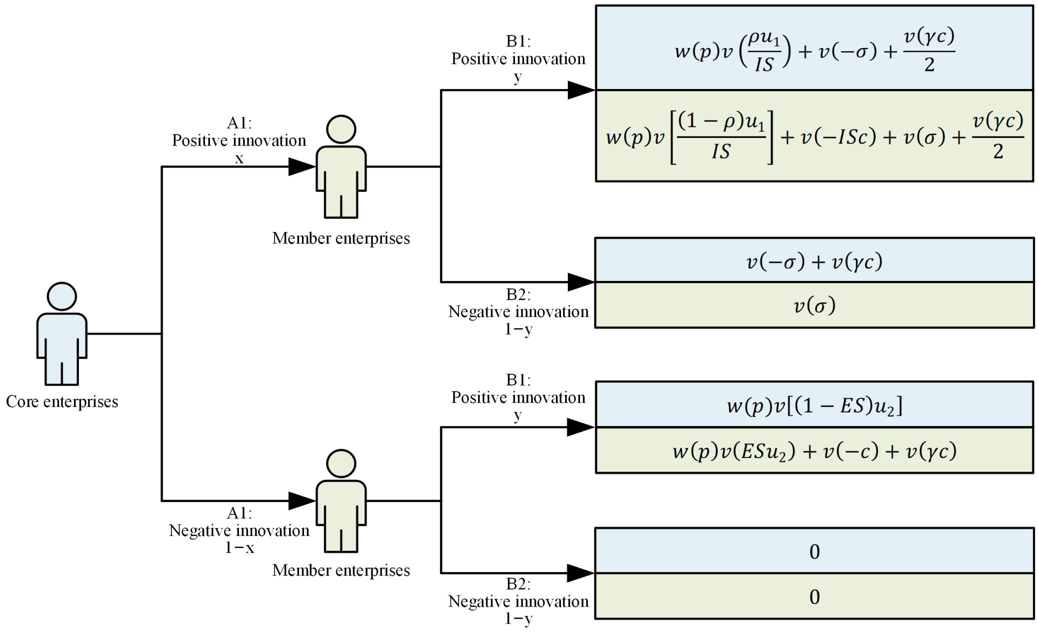


Figure 2. Game tree and payoffs.

Assume that the expected payoff of the core enterprises under the two strategies of positive innovation and negative innovation are U_1 and U_2, respectively, and the average expected payoff is $\overline{U}$, expressed by Equations (4)–(6).

$$U_1 = y\left[w(p)v\left(\frac{\rho u_1}{IS}\right) + v(-\sigma) + \frac{v(\gamma c)}{2}\right] + (1-y)[v(-\sigma) + v(\gamma c)] \tag{4}$$

$$U_2 = yw(p)v[(1-ES)u_2] \tag{5}$$

$$\overline{U} = xU_1 + (1-x)U_2 \tag{6}$$

Assume that the expected payoff of the member enterprises under the two strategies of positive innovation and negative innovation are V_1 and V_2, respectively, and the average expected payoff is $\overline{V}$, expressed by Equations (7)–(9).

$$\begin{gathered} V_1 = x\left\{w(p)v\left[\frac{(1-\rho)u_1}{IS}\right] + v(-ISc) + v(\sigma) + \frac{v(\gamma c)}{2}\right\} \\ +(1-x)[w(p)v(ESu_2) + v(-c) + v(\gamma c)] \end{gathered} \tag{7}$$

$$V_2 = xv(\sigma) \tag{8}$$

$$\overline{V} = yV_1 + (1-y)V_2 \tag{9}$$

According to Equations (6) and (9), the replicated dynamic equations of core enterprises and member enterprises are Equations (10) and (11), respectively.

$$\begin{aligned} F_1 &= \frac{x}{t} = x\left(U_1 - \overline{U}\right) \\ &= x(1-x)\left[v(-\sigma) + v\left(\frac{\rho u_1}{IS}\right)w(p)y - v((1-ES)u_2)w(p)y + v(\gamma c) - \frac{v(\gamma c)y}{2}\right] \end{aligned} \tag{10}$$

$$\begin{aligned} F_2 &= \frac{y}{t} = y\left(V_1 - \overline{V}\right) \\ &= y(1-y)\left\{ \begin{array}{c} v(-c) + v[ESu_2]w(p) + v[-ISc]x - v(-c)x \\ +v\left[\frac{(1-\rho)u_1}{IS}\right]w(p)x - v[ESu_2]w(p)x + v(\gamma c) - \frac{v(\gamma c)x}{2} \end{array} \right\} \end{aligned} \tag{11}$$

To simplify the expressions, define $C_1 = v(-\sigma) + v(\gamma c), C_2 = w(p)v[(1-ES)u_2] - w(p)v\left(\frac{\rho u_1}{IS}\right) + \frac{v(\gamma c)}{2}, M_1 = w(p)v(ESu_2) + v(-c) + v(\gamma c), M_2 = w(p)v\left[\frac{(1-\rho)u_1}{IS}\right] + v(-ISc) + \frac{v(\gamma c)}{2}$. Equations (9) and (10) can be simplified to Equations (12) and (13).

$$F_1 = x(1-x)(C_1 - C_2 y) \tag{12}$$

$$F_2 = y(1-y)(M_1 - M_1 x + M_2 x) \tag{13}$$

where C_1 represents the difference between the innovation subsidy and the innovation incentive granted by the core enterprises when the strategy combination is (A_1, B_2). C_2 is the sum of the difference between the innovation income of the core enterprises when the strategy combination is (A_2, B_1) and (A_1, B_1), and the difference between the innovation subsidy of the core enterprises when the strategy combination is (A_1, B_1) and (A_1, B_2), indicating the harmonious effect of setting innovation subsidies to balance excessive knowledge leakage or insufficient income from collaborative innovation. M_1 represents the net income from the innovation of member enterprises when the strategy combination is (A_2, B_1). M_2 represents the net innovation income of the member enterprises when the strategy combination is (A_1, B_1).

3.4. Stability Analysis of Model Evolution Dynamics

Letting $F_1 = 0$ and $F_2 = 0$, five equilibrium points can be obtained, namely $O(0,0)$, $A(0,1)$, $B(1,0)$, $C(1,1)$, and $D(x_0, y_0)$. Here, $x_0 = \frac{M_2}{M_2 - M_1}$ and $y_o = \frac{C_1}{C_2}$. The fifth equilibrium point exists only when $0 \le x_0 \le 1$ and $0 \le y_o \le 1$. For further local stability analysis, the Jacobian matrix J can be obtained from Equations (12) and (13) as Equation (14), with its determinant and trace as Equations (15) and (16), respectively.

$$J = \begin{bmatrix} \frac{\partial F_1}{\partial x} & \frac{\partial F_1}{\partial y} \\ \frac{\partial F_2}{\partial x} & \frac{\partial F_2}{\partial y} \end{bmatrix} = \begin{bmatrix} (1-2x)(C_1 - C_2 y) & x(x-1)C_2 \\ y(y-1)(M_1 - M_2) & (1-2y)(M_1 - M_1 x + M_2 x) \end{bmatrix} \tag{14}$$

$$\begin{aligned} detJ = (1-2x)(C_1 - C_2 y)(1-2y)(M_1 - M_1 x + M_2 x) \\ -x(x-1)C_2 y(y-1)(M_1 - M_2) \end{aligned} \tag{15}$$

$$trJ = (1-2x)(C_1 - C_2 y) + (1-2y)(M_1 - M_1 x + M_2 x) \tag{16}$$

According to the local stability criterion of the Jacobian matrix, a system's evolutionary stable state exists only when its determinant $detJ > 0$ and trace $trJ < 0$. Based on Equations (14) and (15), the local stability of the system can be classified into the following four scenarios. The stability analysis of equilibrium points under each scenario is shown in Table 2.

Table 2. Stability analysis of equilibrium points under each scenario.

Scenario	Equilibrium Point	*detJ*	Symbol	*trJ*	Symbol	Stability
(1) $C_1 - C_2 > 0$ $M_2 > 0$	$(0,0)$	C_1M_1	Unsure	C_1+M_1	Unsure	Saddle point
	$(0,1)$	$-M_1(C_1 - C_2)$	Unsure	$-M_1 + C_1 - C_2$	Unsure	Saddle point
	$(1,0)$	$-C_1M_2$	Unsure	$-C_1 + M_2$	Unsure	Saddle point
	$(1,1)$	$M_2(C_1 - C_2)$	+	$-M_2 - C_1 + C_2$	−	ESS
(2) $C_1 < 0$ $M_1 < 0$	$(0,0)$	C_1M_1	+	C_1+M_1	−	ESS
	$(0,1)$	$-M_1(C_1 - C_2)$	Unsure	$-M_1 + C_1 - C_2$	Unsure	Saddle point
	$(1,0)$	$-C_1M_2$	Unsure	$-C_1 + M_2$	Unsure	Saddle point
	$(1,1)$	$M_2(C_1 - C_2)$	Unsure	$-M_2 - C_1 + C_2$	Unsure	Saddle point
(3) $C_1 > 0$ $M_2 < 0$	$(0,0)$	C_1M_1	Unsure	C_1+M_1	Unsure	Saddle point
	$(0,1)$	$-M_1(C_1 - C_2)$	Unsure	$-M_1 + C_1 - C_2$	Unsure	Saddle point
	$(1,0)$	$-C_1M_2$	+	$-C_1 + M_2$	−	ESS
	$(1,1)$	$M_2(C_1 - C_2)$	Unsure	$-M_2 - C_1 + C_2$	Unsure	Saddle point
(4) $C_1 - C_2 < 0$ $M_1 > 0$	$(0,0)$	$C_1 - C_2 < 0$	Unsure	C_1+M_1	Unsure	Saddle point
	$(0,1)$	$-M_1(C_1 - C_2)$	+	$-M_1 + C_1 - C_2$	−	ESS
	$(1,0)$	$-C_1M_2$	Unsure	$-C_1 + M_2$	Unsure	Saddle point
	$(1,1)$	$M_2(C_1 - C_2)$	Unsure	$-M_2 - C_1 + C_2$	Unsure	Saddle point

As indicated in Table 2, the joint conditions for $C(1,1)$ and $A(1,0)$ to be Evolutionarily Stable Strategies (ESSs) are $C_1 - C_2 > 0$ and $C_1 > 0$. From this, it can be inferred that ensuring the positive innovation of the core enterprises is crucial, with the key consideration being that the net prospect payoff of independent innovation is not less than 0, and the net prospect payoffs of collaborative innovation are greater than those of individual innovation. Additionally, the joint conditions for $C(1,1)$ and $B(0,1)$ to be ESSs are $M_1 > 0$ and $M_2 > 0$. Therefore, the key to ensuring the positive innovation of member enterprises lies in the assurance that the net prospect payoff is not less than 0, whether engaged in collaborative or individual innovation.

4. Numerical Analysis

Based on the above analysis, to more intuitively describe the dynamic influence of different parameters on collaborative innovation, this study integrates the conditions from scenario (1) and scenario (2) to formulate scenario (5). In scenario (5), both $O(0,0)$ and $C(1,1)$ are ESSs, with $D(x_0, y_0)$ serving as the equilibrium point. The stability analysis of the equilibrium point is presented in Table 3.

Table 3. Stability analysis of equilibrium points under scenario (5).

Scenario	Equilibrium Point	*detJ*	Symbol	*trJ*	Symbol	Stability
(5)	$(0,0)$	C_1M_1	+	C_1+M_1	−	ESS
$C_1 - C_2 > 0$	$(0,1)$	$-M_1(C_1 - C_2)$	+	$-M_1 + C_1 - C_2$	+	Unstable point
$C_1 < 0$	$(1,0)$	$-C_1M_2$	+	$-C_1 + M_2$	+	Unstable point
$M_2 > 0$	$(1,1)$	$M_2(C_1 - C_2)$	+	$-M_2 - C_1 + C_2$	−	ESS
$M_1 < 0$	(x_0, y_o)	$\frac{M_2M_1}{M_2-M_1}\frac{C_1(C_1-C_2)}{C_2}$	−	$-(M_2 + M_1)\frac{C_1}{C_2}$	Unsure	Saddle point

On the premise that scenario (5) is satisfied, this study leverages insights from prior research [7,13,14,31,32] to establish initial parameter values as follows: $u_1 = 12$, $u_2 = 6$, $c = 3$, $\rho = 0.5$, $\sigma = 1$, $\gamma = 0.5$, $\alpha = 0.5$, $\beta_1 = 0.5$, $\beta_2 = 0.5$, $a = 0.88$, $b = 0.88$, $\lambda = 2.25$, $p = 0.7$, $r = 0.7$. On this basis, MATLAB R2021b is used to simulate the strategy evolution of different initial states, and the simulation results are compared with empirical observation results to verify the applicability of data collection to the model, as illustrated in Figure 3.

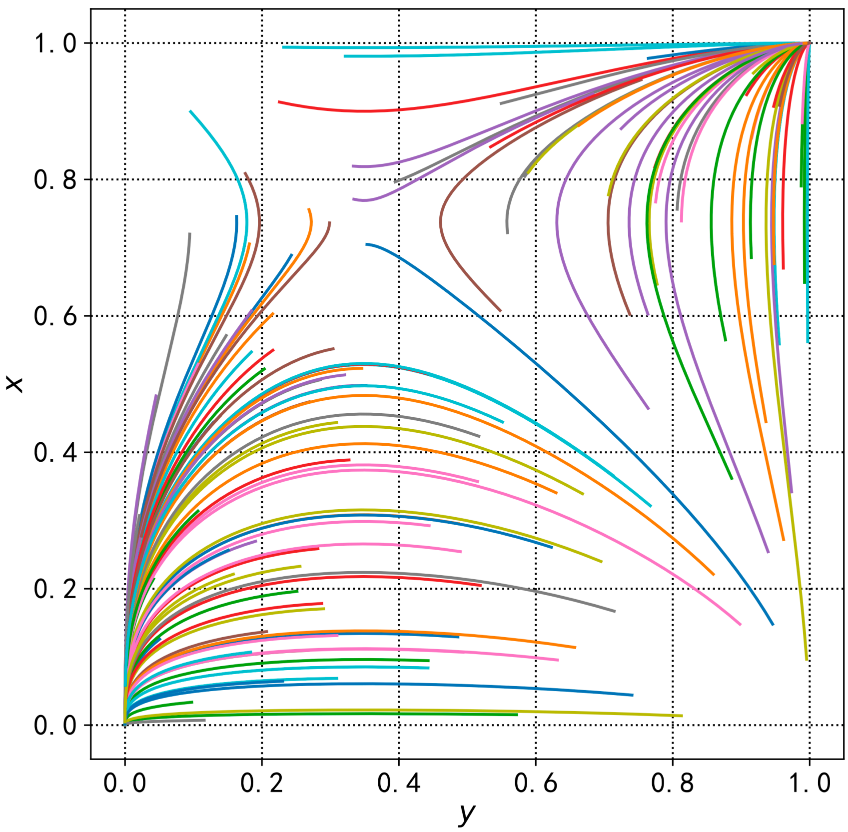


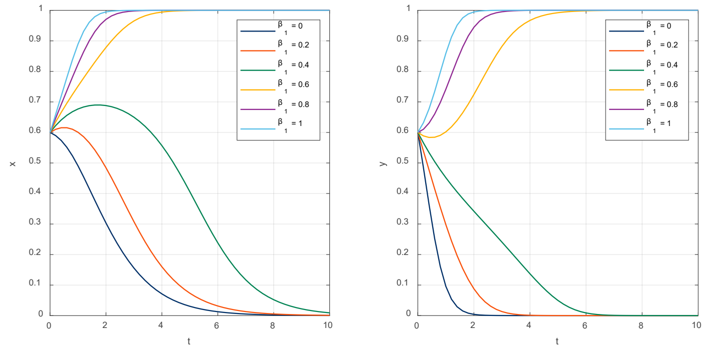
Figure 3. Strategy evolution in different initial states (represented by different colors).

Furthermore, MATLAB R2021b is employed to simulate strategy evolution by varying individual parameters while maintaining the initial values of other parameters constant. The outcomes are outlined below.

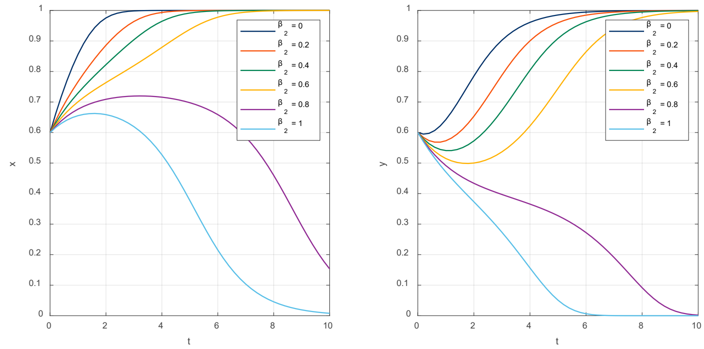
4.1. The Impact of Knowledge Spillover Effects and DC Technology Application

β_1 represents the knowledge sharing coefficient, β_2 represents the knowledge leakage coefficient, and (a) and (b) in Figure 4 represent the strategy evolution of β_1 and β_2 in the range of 0 to 1, respectively. It can be seen from Figure 4a that x and y converge to 1 when β_1 is greater than a certain critical value, and the convergence speeds up with the increase in β_1. As can be seen from Figure 4b, when β_2 is less than a critical value, x and y converge to 0, and the smaller β_2 is, the faster the convergence rate will be. It is worth noting that x tends to converge to 1 more than y in the early stage of evolution, and the tendency of y to turn to 1 is significantly influenced by x.

Symbol α represents the DC technology application coefficient, which enhances the knowledge spillover effects. Figure 5 shows the strategy change of α in the range of 0 to 1 under different combinations of knowledge leakage and knowledge sharing. In Figure 5a, the effects of knowledge sharing and knowledge leakage are the same. It can be seen that x and y converge to 1 when α is greater than a certain critical point, and the convergence speed also increases significantly when α increases. In Figure 5b, the effect of knowledge sharing is smaller than that of knowledge leakage. It can be seen that, compared with the result in Figure 5a, the critical value of α increases, and the increase in α has no significant effect on the convergence rate when it is less than the critical value. In addition, changes in α have almost the same effect on the evolution of x and y.

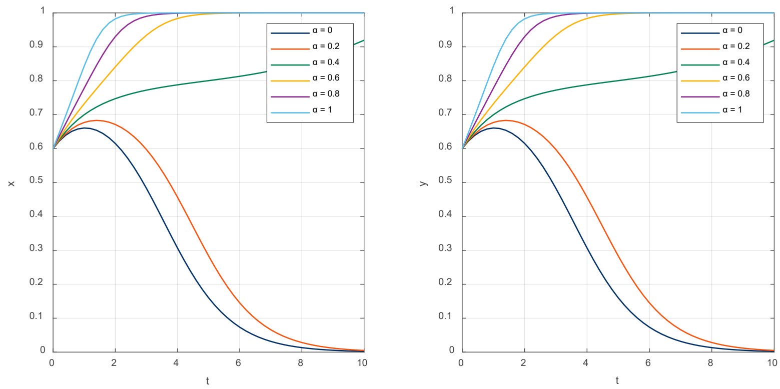


(**a**)

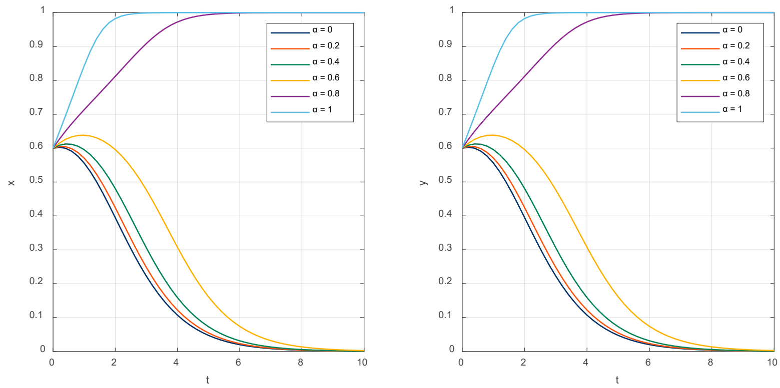


(**b**)

Figure 4. Strategy evolution under different knowledge spillover effects. (**a**) Strategy evolution under different β_1 values; (**b**) Strategy evolution under different β_2 values.



(**a**)



(**b**)

Figure 5. Strategy evolution under different α values. (**a**) $\beta_1 = 0.5,\ \beta_2 = 0.5$; (**b**) $\beta_1 = 0.3,\ \beta_2 = 0.7$.

4.2. The Impact of Managerial Cognitive Structures

Symbol a is the gain sensitivity coefficient of enterprise managers, and the smaller a is, the more risk averse the manager is when facing gain. Figure 6 shows the strategy evolution of a in the range of 0 to 1. As can be seen from Figure 6, when a is less than a certain critical value, x and y begin to converge toward 0, and the smaller a is, the faster the convergence speed will be. In particular, the results of x are more sensitive to changes in a.

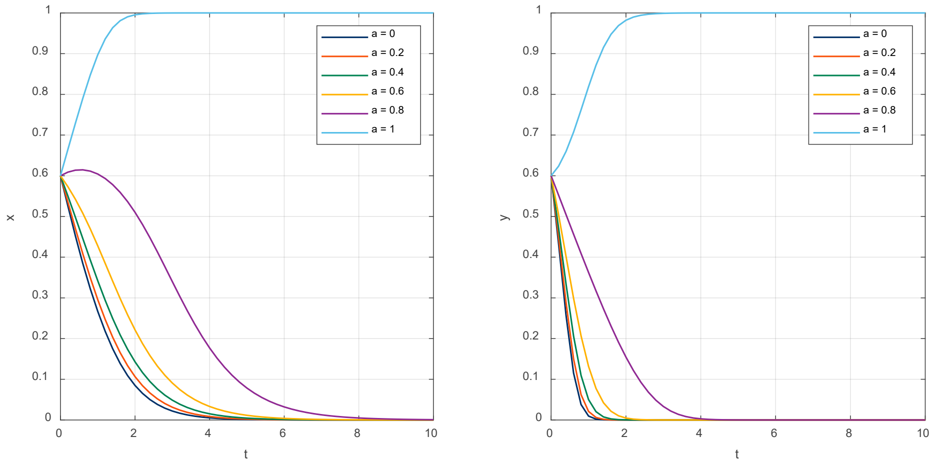


Figure 6. Strategy evolution under different a values.

b is the loss sensitivity coefficient of enterprise managers. The smaller b is, the greater the risk appetite the manager is when facing loss. Figure 7 shows the strategy evolution of b in the range of 0 to 1. As can be seen from Figure 7, when b is less than a certain critical value, x and y begin to converge toward 1, and the larger b is, the faster the convergence rate will be. In particular, the results of y are more sensitive to changes in b.

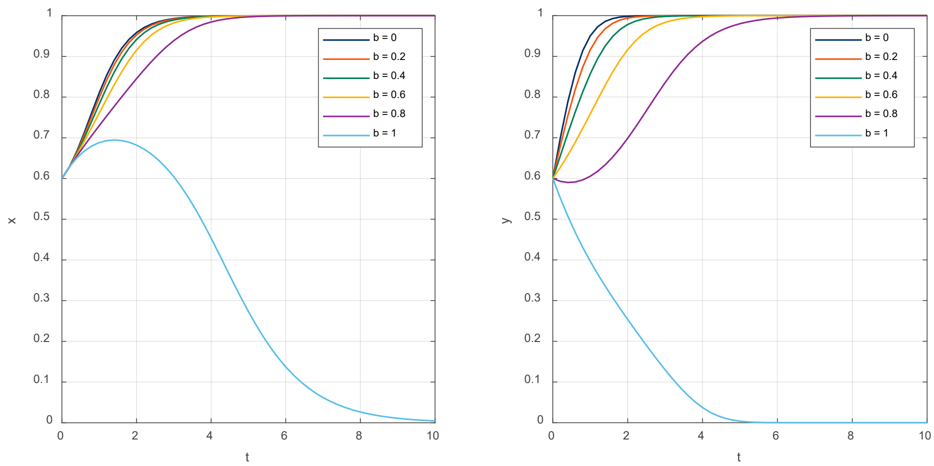


Figure 7. Strategy evolution under different b values.

λ represents the loss aversion coefficient, which reflects the degree to which managers are more sensitive to the perception of loss than the perception of gain under uncertain conditions. The greater the λ, the more averse the manager is to loss. Figure 8 shows the change of strategy under different λ values. As can be seen from Figure 8, the critical value of λ exists between 2.2 and 2.4. When λ is greater than the critical value, x and y begin to converge towards 0, and the convergence speed accelerates with the increase in λ.

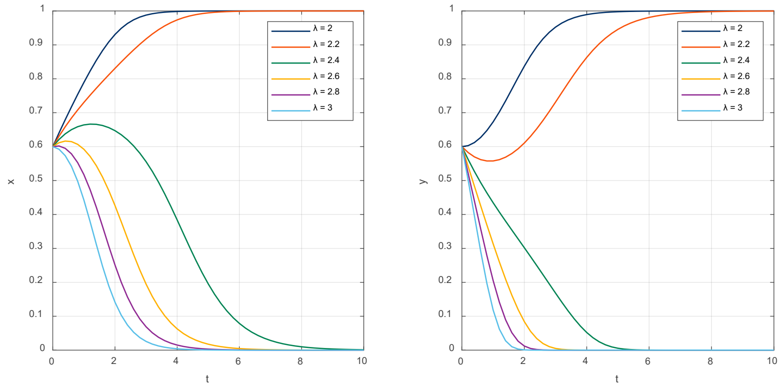


Figure 8. Strategy evolution under different λ values.

4.3. The Impact of Innovation Incentive Mechanisms

ρ is the income distribution ratio between the core enterprises and the member enterprises during collaborative innovation. Figure 9 shows the strategy evolution of different ρ values from 0 to 1. As can be seen from Figure 9, when ρ is 0.4, x and y gradually converge to 1. As ρ moves away from 0.4, both x and y converge to 0 and converge faster. A distribution coefficient larger or smaller than 0.4 initially causes x or y to converge toward 1 but soon converges toward 0.

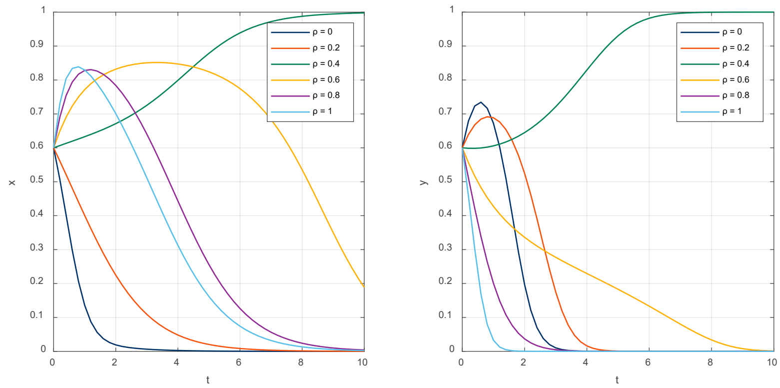


Figure 9. Strategy evolution under different ρ values.

σ is the innovation incentive fund issued by the core enterprises when they actively innovate. When σ ranges from 0 to 1, the result of strategy evolution is shown in Figure 10. As can be seen from Figure 10, the convergence of x and y changes from 1 to 0 as σ increases from 0 and gradually passes the critical value between 0.8 and 1.

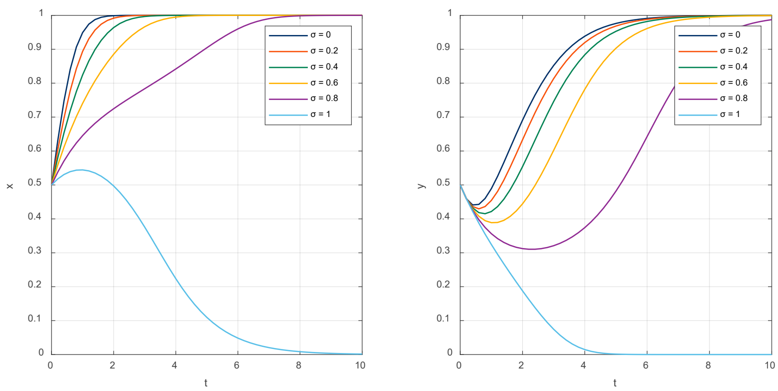


Figure 10. Strategy evolution under different σ values.

γ is the innovation subsidy coefficient of owners, and Figure 11 shows the evolution of strategies with γ values in the range of 0 to 1. As can be seen from Figure 11, there is a critical value between 0.4 and 0.6, and x and y converge to 1 when γ is greater than the critical value. The higher the γ value, the faster x and y converge to 1.

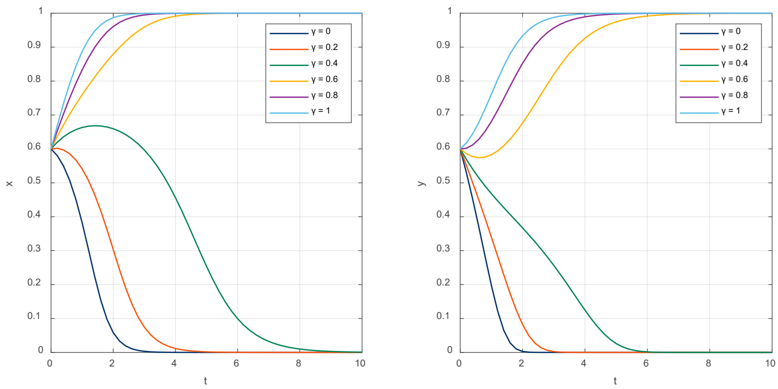


Figure 11. Strategy evolution under different γ values.

5. Discussion

To sum up, the evolutionary game model indicates that collaborative innovation in the CSC under DC is the result of a multifaceted systemic process, demanding comprehensive and multidimensional sustained coordination. The identification of multiple equilibrium points reveals that to cultivate a dynamic and innovative construction supply chain, core enterprises should focus on creating conditions where the benefits of both independent and collaborative innovation are maximized. This involves fostering an environment rich in resources and support for innovation, ensuring that any new initiatives or technologies developed in-house yield a positive net payoff, and that collaborative efforts with other entities enhance overall performance. For member enterprises, it is crucial to maintain a strategic balance where innovation, whether pursued independently or in collaboration, consistently provides positive returns. Encouraging a culture of innovation, investing in cutting-edge technologies, and building strong, cooperative relationships within the supply chain are key steps. By strategically aligning these efforts, enterprises can ensure robust, sustainable growth and maintain a competitive edge. Finally, numerical simulation results shed light on the complexities of this mechanism from the following three distinct perspectives.

The analysis of knowledge spillover effects underscores that knowledge sharing, by reducing innovation costs and augmenting innovation returns, serves as the primary driver of collaborative innovation advantages, effectively fostering the emergence of collaborative innovation patterns [33]. However, knowledge leakage represents the "Achilles' heel" of knowledge sharing [34]. While knowledge leakage may not directly impair the benefits of collaborative innovation, it heightens the potential risks for member enterprises during positive innovation and the chances of core enterprises benefiting without contributing, thereby indirectly impeding the formation of collaborative innovation patterns [35]. Therefore, enhancing knowledge sharing and mitigating knowledge leakage are essential for advancing collaborative innovation in the CSC and are essential prerequisites for leveraging the application of DC technology. This is because the application of DC technology is essentially neutral; it can amplify the positive effects of knowledge spillover but may also exacerbate its negative impacts. The strategy evolution simulation conducted in this study reveals that under different knowledge spillover conditions, the use of DC technology has different impacts. This suggests that while the application of DC technology can play a "supportive" role, it is not a complete "panacea". As highlighted by [27], the challenge of safeguarding intellectual property has emerged as a barrier to collaboration based on BIM. Other studies have indicated that a partnership-based contract model is more conducive to BIM-based collaborative innovation [24]. Thus, in line with academics' arguments that the "hard" issues of solely deploying digital technology are not the crux under DC, this study further underscores the importance of addressing the "soft" issues of digital technology governance from a knowledge management perspective.

The analysis of managerial cognitive structures illustrates that risk-averse managers prioritize stability and incremental improvements, while risk-seeking managers aim for transformative changes and high-impact innovations, and different types of managers have different degrees of influence on different enterprises. Risk aversion when facing potential gains significantly hampers the proactive innovation in the CSC, particularly impacting decision-making within core enterprises. Therefore, actively guiding the perceived utility of core enterprises emerges as a crucial avenue for driving collaborative innovation. Additionally, a willingness to take risks in the face of losses contributes to stimulating the innovation orientation in the CSC, with a more pronounced influence on decision-making within member enterprises. According to performance feedback theory, when performance returns exceed expectations, stakeholders and leadership become more apprehensive about the risk of failure rather than the prospects of success. This tendency makes managers risk-averse during the innovation process, resulting in greater organizational inertia [36]. Conversely, negative performance triggers problem searching, prompting the organization to transition into a problem-solving mode after identifying performance issues, thereby empowering managers to take on more risks with input from a broader group of stakeholders [37]. In summary, collaborative innovation under DC is likened to a "game for the brave", rejecting outdated practices. Embracing challenges and risks under the guidance of long-term goals are pivotal in navigating environmental uncertainty. This finding is consistent with the conclusions drawn by Pham et al. [38], which highlight the benefits of transformational leadership in promoting organizational learning and fostering innovation.

The analysis of innovation incentive mechanisms highlights the close relationship between income distribution and the persistence of collaborative innovation [39]. Establishing a moderate and equitable incomes distribution ratio is a pivotal factor in shaping a collaborative innovation framework in the CSC. Unidirectional high-allocation models, wherein resources and responsibilities are disproportionately distributed, often result in short-term engagement from the party receiving fewer benefits. This limited commitment highlights the critical need for frameworks based on the principles of mutual benefit and distribution according to work. Such principles ensure that all parties involved derive equitable value from the collaboration, thereby fostering enduring partnerships characterized by sustained mutual support and cooperation. By prioritizing balanced contributions and shared rewards, these modes create a more stable and resilient foundation for long-term collaboration. It is essential to note that overly generous and unconditional incentives offered to member enterprises by core enterprises may inadvertently hinder the continuous development of collaborative innovation patterns in the CSC. On one hand, the overinvestment of incentive funds by core enterprises may increase their innovation expenses, rendering sustained collaborative innovation challenging. On the other hand, a lack of clear standards for innovation incentives may fail to effectively enhance the motivation for innovation of member enterprises. When devising incentive mechanisms for project-based supply chain cross-organizational collaborative innovation, it is essential to consider the direct correlation between mutual preferences and efforts throughout the project stages [40]. Conversely, subsidy measures implemented by owners significantly promote promoting collaborative innovation in the CSC. Such innovation subsidies not only improve the overall benefits of collaborative innovation but also make up for the lack of support for positive innovation. Active external governance effectively incentivizes active participation in collaborative innovation among various stakeholders in the CSC [41].

6. Conclusions and Implications

This study constructs a PT-based evolutionary game model of collaborative innovation in the CSC under DC. It reveals the dynamic effects of DC technology application, knowledge spillover effects, managerial cognitive structures, and innovation incentive mechanisms, thereby broadening the research perspective under DC. Consequently, this study provides the following substantive management implications to foster the robust development of collaborative innovation.

Firstly, core enterprises in the CSC should actively formulate a reasonable profit distribution mechanism to provide a solid foundation for the stability of the collaborative pattern. Simultaneously, when designing incentive measures, the reciprocity principle must be deeply considered to ensure the sustainability of the innovation incentive system [42]. In addition, a comprehensive joint development agreement should be consciously established, including intellectual property ownership, shared rights, and the responsibilities of all parties. At the managerial level, top leaders of core enterprises must go beyond satisfaction with the status quo, actively respond to market turbulence and challenges, and actively seek breakthroughs in innovation and transformation [43].

Secondly, while strengthening collaborative knowledge exchange, member enterprises in the CSC should establish a robust management mechanism for protecting intellectual property rights to promote the sustainability of collaborative innovation. For example, by establishing a secure information sharing platform and adopting hierarchical management of rights, knowledge can be shared within a controllable range. Moreover, in external cooperation, strict confidentiality agreements should be signed, and project-level security reviews and monitoring should be implemented. Under these circumstances, the active adoption of DC technology will contribute to enhancing knowledge management efficiency, significantly increasing collaborative win–win benefits and stimulating the collaborative innovation momentum in the CSC [44]. Additionally, managers of member enterprises should cultivate a long-term vision for benefits, especially when formulating strategies and investment plans, emphasizing the future potential of innovation transformation.

Thirdly, external governance from owners is a crucial method to promote collaborative innovation in the CSC. Faced with highly uncertain innovation risks, introducing innovative subsidy measures can effectively incentivize enterprises in the CSC to engage in digital technology innovation by improving overall benefits. Furthermore, external proactive governance can reduce the negative impact of fairness considerations in the CSC on collaborative innovation motivation, reconciling the contradictory relationship between interest distribution and effort mismatch [42].

While this study contributes to the understanding of promoting the healthy development of collaborative innovation in the CSC under DC, it has limitations. The paper considers knowledge spillover effects as a key factor in the collaborative innovation under DC. However, the existing literature suggests that digitalization has broader impacts on collaborative innovation, such as the standardization of technological features, regularization of investment budgets, and formalization of innovation procedures. Future research could consider more complex factors [45]. Moreover, this study focuses on the collaboration model in the CSC. However, different collaboration models will trigger different theoretical logics, and a more comprehensive analysis will help explore diverse approaches to enhance the level of innovation. Finally, when transforming complex practical problems into relatively simple mathematical models, it is particularly critical to clarify the boundary conditions applicable to the models, and future research needs to be carried out according to local conditions and time conditions.

Author Contributions: Methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft, writing—review and editing, visualization, C.D.; formal analysis, writing—original draft, writing—review and editing, H.L.; conceptualization, methodology, writing—original draft, supervision, project administration, Y.C.; investigation, resources, data curation W.Q. All authors have read and agreed to the published version of the manuscript.

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References

1. Turner, C.J.; Oyekan, J.; Stergioulas, L.; Griffin, D. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Trans. Ind. Inform.* **2021**, *17*, 746–756. [CrossRef]
2. Tetik, M.; Peltokorpi, A.; Seppänen, O.; Holmström, J. Direct Digital Construction: Technology-Based Operations Management Practice for Continuous Improvement of Construction Industry Performance. *Autom. Constr.* **2019**, *107*, 102910. [CrossRef]
3. Xue, X.; Zhang, R.; Yang, R.; Dai, J. Innovation in Construction: A Critical Review and Future Research. *Int. J. Innov. Sci.* **2014**, *6*, 111–126. [CrossRef]
4. Mukundan, R.; Thomas, S. Collaborative and Open Innovation: Supply Chain Planning as an Effective Source. *Int. J. Indian Cult. Bus. Manag.* **2016**, *12*, 128. [CrossRef]
5. Attaran, M.; Attaran, S. Collaborative Supply Chain Management: The Most Promising Practice for Building Efficient and Sustainable Supply Chains. *Bus. Process Manag. J.* **2007**, *13*, 390–404. [CrossRef]
6. Koc, K.; Gurgun, A.P. Stakeholder-Associated Life Cycle Risks in Construction Supply Chain. *J. Manag. Eng.* **2021**, *37*, 04020107. [CrossRef]
7. Qiao, S.; Wang, Q.; Guo, Z.; Guo, J. Collaborative Innovation Activities and BIM Application on Innovation Capability in Construction Supply Chain: Mediating Role of Explicit and Tacit Knowledge Sharing. *J. Constr. Eng. Manag.* **2021**, *147*, 04021168. [CrossRef]
8. Oraee, M.; Hosseini, M.R.; Edwards, D.J.; Li, H.; Papadonikolaki, E.; Cao, D. Collaboration Barriers in BIM-Based Construction Networks: A Conceptual Model. *Int. J. Proj. Manag.* **2019**, *37*, 839–854. [CrossRef]
9. Papadonikolaki, E. Loosely Coupled Systems of Innovation: Aligning BIM Adoption with Implementation in Dutch Construction. *J. Manag. Eng.* **2018**, *34*, 05018009. [CrossRef]
10. Martínez-Noya, A.; García-Canal, E. Innovation Performance Feedback and Technological Alliance Portfolio Diversity: The Moderating Role of Firms' R&D Intensity. *Res. Policy* **2021**, *50*, 104321. [CrossRef]
11. Oraee, M.; Hosseini, M.R.; Namini, S.B.; Merschbrock, C. Where the Gaps Lie: Ten Years of Research into Collaboration on BIM-Enabled Construction Projects. *Constr. Econ. Build.* **2017**, *17*, 121–139. [CrossRef]
12. Liu, H.; Skibniewski, M.J.; Ju, Q.; Li, J.; Jiang, H. BIM-Enabled Construction Innovation through Collaboration: A Mixed-Methods Systematic Review. *Eng. Constr. Archit. Manag.* **2020**, *28*, 1541–1560. [CrossRef]
13. Qian, Y.; Yu, X.; Chen, X.; Song, M. Research on Stability of Major Engineering Technology Innovation Consortia Based on Evolutionary Game Theory. *Comput. Ind. Eng.* **2023**, *186*, 109734. [CrossRef]
14. Zheng, Y.; Mei, L. How to Promote the Adoption of Intelligent Spray Technology in Farmers' Cooperatives?—Based on the Perspective of Evolutionary Game. *Heliyon* **2023**, *9*, e19897. [CrossRef]
15. Jasiński, A. Impact of BIM Implementation on Architectural Practice. *Archit. Eng. Des. Manag.* **2021**, *17*, 447–457. [CrossRef]
16. Chen, Y.; Ding, C. Multidimensional Evolutionary Analysis of China's BIM Technology Policy Based on Quantitative Mapping. *Archit. Eng. Des. Manag.* **2023**, *20*, 578–595. [CrossRef]
17. He, R.; Li, M.; Gan, V.J.L.; Ma, J. BIM-Enabled Computerized Design and Digital Fabrication of Industrialized Buildings: A Case Study. *J. Clean. Prod.* **2021**, *278*, 123505. [CrossRef]
18. Nguyen, T.D.; Adhikari, S. The Role of BIM in Integrating Digital Twin in Building Construction: A Literature Review. *Sustainability* **2023**, *15*, 10462. [CrossRef]
19. Ding, L. The connotation and frame system of digital construction. *Constr. Enterp. Manag.* **2022**, *2*, 86–89.
20. Okpalaoka, C.I. Research on the Digital Economy: Developing Trends and Future Directions. *Technol. Forecast. Soc. Chang.* **2023**, *193*, 122635. [CrossRef]
21. Li, Y.; Song, Y.; Wang, J.; Li, C. Intellectual Capital, Knowledge Sharing, and Innovation Performance: Evidence from the Chinese Construction Industry. *Sustainability* **2019**, *11*, 2713. [CrossRef]
22. Xue, X.; Tan, X.; Huang, Q.; Zhu, H.; Chen, J. Exploring the Innovation Path of the Digital Construction Industry Using Mixed Methods. *Buildings* **2022**, *12*, 1840. [CrossRef]
23. Aghimien, D.O.; Aigbavboa, C.O.; Oke, A.E. Critical Success Factors for Digital Partnering of Construction Organisations—A Delphi Study. *Eng. Constr. Archit. Manag.* **2020**, *27*, 3171–3188. [CrossRef]
24. Hall, D.M.; Algiers, A.; Levitt, R.E. Identifying the Role of Supply Chain Integration Practices in the Adoption of Systemic Innovations. *J. Manag. Eng.* **2018**, *34*, 04018030. [CrossRef]
25. Simonsson, J.; Magnusson, M. Collaboration Challenges in Digital Service Innovation Projects. *Int. J. Autom. Technol.* **2018**, *12*, 499–506. [CrossRef]
26. Kattel, R.; Lember, V.; Tõnurist, P. Collaborative Innovation and Human-Machine Networks. *Public Manag. Rev.* **2020**, *22*, 1652–1673. [CrossRef]
27. Avila, P.; Mullon, C. Evolutionary Game Theory and the Adaptive Dynamics Approach: Adaptation Where Individuals Interact. *Philos. Trans. R. Soc. B Biol. Sci.* **2023**, *378*, 20210502. [CrossRef] [PubMed]
28. Yuan, R.; Wang, Y.; Qian, Y.; Yu, X. Evolutionary Game Analysis on Cooperative Behavior of Major Projects' Technology Innovation Subjects under General Contracting Mode. *Buildings* **2024**, *14*, 1280. [CrossRef]
29. Traulsen, A.; Glynatsi, N.E. The Future of Theoretical Evolutionary Game Theory. *Philos. Trans. R. Soc. B Biol. Sci.* **2023**, *378*, 20210508. [CrossRef]
30. Kahneman, D.; Tversky, A. Prospect Theory: An Analysis of Decision under Risk. *Econometrica* **1979**, *47*, 263–291. [CrossRef]

31. Tversky, A.; Kahneman, D. Advances in Prospect Theory: Cumulative Representation of Uncertainty. *J. Risk Uncertain.* **1992**, *5*, 297–323. [CrossRef]
32. Qin, S. The Non-Cooperative Game and Cooperative Game Between Independent Innovation Firm and Imitative Innovation Firm. *J. Knowl. Econ.* **2023**. [CrossRef]
33. Shen, B. The Influence of Endogenous Knowledge Spillovers on Open Innovation Cooperation Modes Selection. *Wirel. Pers. Commun.* **2018**, *102*, 2701–2713. [CrossRef]
34. Vafaei-Zadeh, A.; Hanifah, H.; Foroughi, B.; Salamzadeh, Y. Knowledge Leakage, an Achilles' Heel of Knowledge Sharing. *Eurasian Bus. Rev.* **2019**, *9*, 445–461. [CrossRef]
35. Bloom, N.; Schankerman, M.; Van Reenen, J. Identifying Technology Spillovers and Product Market Rivalry. *Econometrica* **2013**, *81*, 1347–1393. [CrossRef]
36. He, L.; Huang, L.; Yang, G. Invest in Innovation or Not? How Managerial Cognition and Attention Allocation Shape Corporate Responses to Performance Shortfalls. *Manag. Organ. Rev.* **2021**, *17*, 815–850. [CrossRef]
37. Saraf, N.; Dasgupta, S.; Blettner, D.P. How Do Managerial Perceptions of Performance Feedback Affect Innovation? *Strateg. Organ.* **2022**, *20*, 451–480. [CrossRef]
38. Pham, H.T.; Pham, T.; Truong Quang, H.; Dang, C.N. Impact of Transformational Leadership on Green Learning and Green Innovation in Construction Supply Chains. *Eng. Constr. Archit. Manag.* **2022**, *30*, 1883–1901. [CrossRef]
39. Hu, C.; Liu, P.; Yang, H.; Yin, S.; Ullah, K.; Hu, C.; Liu, P.; Yang, H.; Yin, S.; Ullah, K. A Novel Evolution Model to Investigate the Collaborative Innovation Mechanism of Green Intelligent Building Materials Enterprises for Construction 5.0. *AIMS Math.* **2023**, *8*, 8117–8143. [CrossRef]
40. Wu, G.-D. Project-Based Supply Chain Cooperative Incentive Based on Reciprocity Preference. *Int. J. Simul. Model.* **2014**, *13*, 102–115. [CrossRef] [PubMed]
41. Zeng, X.; Li, S.; Yin, S.; Xing, Z. How Does the Government Promote the Collaborative Innovation of Green Building Projects? An Evolutionary Game Perspective. *Buildings* **2022**, *12*, 1179. [CrossRef]
42. Jiang, W.; Yuan, L.; Wu, L.; Guo, S. Carbon Emission Reduction and Profit Distribution Mechanism of Construction Supply Chain with Fairness Concern and Cap-and-Trade. *PLoS ONE* **2019**, *14*, e0224153. [CrossRef]
43. Pham, H.; Pham, T.; Dang, C.N. Assessing the Importance of Transformational Leadership Competencies and Supply Chain Learning to Green Innovation: Construction Practitioners' Perspectives. *Constr. Innov.* **2021**, *22*, 1138–1154. [CrossRef]
44. Saini, M.; Arif, M.; Kulonda, D.J. Challenges to Transferring and Sharing of Tacit Knowledge within a Construction Supply Chain. *Constr. Innov.* **2019**, *19*, 15–33. [CrossRef]
45. Urbinati, A.; Chiaroni, D.; Chiesa, V.; Frattini, F. The Role of Digital Technologies in Open Innovation Processes: An Exploratory Multiple Case Study Analysis. *RD Manag.* **2020**, *50*, 136–160. [CrossRef]